NASA CR-54889

GA-6897

MEASUREMENT OF NEUTRON SPECTRA IN LIQUID HYDROGEN

by

G. D. Trimble and A. E. Profio

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-6217

GENERAL ATOMIC

DIVISION OF

GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608, SAN DIEGO 12, CALIFORNIA

Requests for copies of this report should be referred to

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Attention: AFSS-A
Washington, D. C. 20546

GENERAL ATOMIC

DIVISION OF

GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608, SAN DIEGO, CALIFORNIA 92112

NASA CR-54889
GA-6897

MEASUREMENT OF NEUTRON SPECTRA IN LIQUID HYDROGEN

Quarterly Progress Report for the Period Ending December 17, 1965

Work done by:

J. H. Audas
J. R. Beyster
J. H. Diaz
G. K. Houghton
A. E. Profio
J. W. Riggs
J. C. Sayer
G. D. Trimble

Report written by:

G. D. Trimble
A. E. Profio

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 7, 1966

Contract NAS 3-6217

Technical Management
NASA-Lewis Research Center
Advanced Development and Evaluation Division
Nuclear Rocket Technology Office
John C. Liwosz

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

This is the second scheduled quarterly report of the work being performed on the measurement of neutron spectra in liquid hydrogen for the National Aeronautics and Space Administration under Contract No. NAS 3-6217. The first quarterly report for the period June 18 to September 17, 1965, was waived by NASA-Lewis in favor of a monthly report because the Principal Investigator was working, with approval of NASA-Lewis, on another NASA contract (SNPC-27) during the month of July and could spend only a minimal amount of time on the subject contract during the month of August for the same reason. Therefore, this report is, in effect, a semiannual report and it includes a summary of the results for that period of time.

II. LIQUID HYDROGEN FACILITY

The liquid hydrogen facility is a complex of the following components:

1. Liquid hydrogen cryostat
2. Valve package
3. Connections from the LH_2 cryostat to the valve package such as the flexible vent lines and the vacuum jacketed fill and dump line.
4. Gas cylinders and plumbing for distributing the gaseous nitrogen or gaseous helium for purging and commonly referred to as the "bottle farm".
5. Transfer lines from the valve package to the LH_2 supply dewar.
6. Remote control console
7. Support structure for the LH_2 cryostat.

Much of the work to be performed on this contract required the resetup of the LH_2 facility. The following sections describe the various components of the system and give in some detail the problems, tests, and modifications that were necessary to reinstate the LH_2 facility to its configuration as of the date of this report.

A. Liquid Hydrogen Experimental Cryostat

The LH_2 experimental cryostat is the "heart" of the LH_2 facility. It contains 160 gallons of liquid hydrogen when completely filled. It is compartmented in such a way as to vary the thickness of hydrogen which the fast neutrons must penetrate before escaping by the probe tube down the flight path to the detector. The cryostat is insulated by 90 layers, each of which is composed of aluminum foil and glass fiber paper. The multi-layered (super) insulation is between the inner and outer dewar and it is under vacuum. During the fifteen months between the end of the last contract and the start of the present contract, the vacuum had, of course, deteriorated. To perform the pumpdown required building a vacuum system composed of a vacuum valve, forepump, diffusion pump, vacuum readout system, and flexible bellows. Numerous safety measures with backup precautions were necessary to insure against such things as cracking the oil in the diffusion pump and contaminating the multilayer insulation space. The multilayer insulation contains numerous interstitial spaces and constitutes an excellent trap for the various gas molecules. Pumpdown of this multilayer insulation space required several weeks to obtain a 1.8×10^{-5} mm of Hg vacuum which is satisfactory and as good as during the experimental work conducted under NAS 3-4214; therefore, pumping has been discontinued temporarily. When the cryostat is in position for the LH_2 measurements, pumping of the multilayer insulation will be resumed in an effort to obtain a vacuum better than 1.8×10^{-5} mm of Hg.

A vacuum of 1.8×10^{-5} mm of Hg is adequate for the experiment, however, a better vacuum improves the insulation properties.

The Buna-N "O" rings in the vacuum valve attached to the LH_2 cryostat were replaced prior to pumpdown since the cryostat has been in a high radiation field area for over 15 months and these "O" rings could have sustained radiation damage.

B. Valve Package

The valve package and the associated gas, vacuum, and transfer lines had to be completely cleaned before being placed in service. It is perhaps worthwhile to elucidate upon the details of this procedure and the purpose and careful attention that this procedure requires so that a better understanding of this problem can be obtained. The valve package contains ten valves which see LH_2 or cold gas. These valves are electro-pneumatic remotely-operated extended stem valves with the dump and fill valves vacuum jacketed. They are of the metal-to-metal seal type. The valve package also contains three remote-operated solenoid warm gas valves for emergency purge. Directly connected to the valve package from two different locations remoted 30 and 60 ft. respectively are gas lines containing both remote-operated solenoid gas valves and throttleable hand valves for purging, evacuation, operation of the pneumatic valves, and remote readout of the pressure-vacuum of the system. Also connected to the valve package is a 40 ft. dump line, a 40 ft. vent line and a 30 ft. transfer line.

The valves which control the flow of cryogenic liquids or gas must be in proper working order. The liquid hydrogen system must also be free of all matter which would jam or clog the valves and flow passages. The system must be dry and free of water since ice formed during the LH_2 or LN_2 runs could lodge in the valve seats. Care has been taken to ensure that no dust or foreign material has entered the valve package and gas lines by sealing all connections during this inactive period. This does not preclude the possibility that some foreign material may have entered the system during the LH_2 experiments in August 1964 or that corrosion of the 3-in. diameter copper vent line has not taken place.

The procedure for cleaning the valve package and associated gas and transfer lines is outlined below:

1. The valve seats of the cold valves were vacuumed through external connections where possible.

2. The three solenoid-operated warm gas valves on the valve package were disassembled and the valve stem seals and seats of these valves were carefully inspected and cleaned, where necessary. During the previous contract we had difficulty with gas flow through one of the solenoid-operated warm gas valves. The diaphragm on these valves contain two holes diametrically opposite with one slightly larger than the other. One is for gas flow and the other for alignment with an aligning pin. During disassembly it was found that the diaphragm had been installed so that these holes had been interchanged; when this was corrected the problem was eliminated.

3. Every line in the valve package and all lines connected to the valve package were flushed with dry nitrogen gas and the gas lines sealed.

4. To break loose attached particles the valve package was "cold-shocked" and flushed with LN_2. LN_2 was allowed to flow out of the 3-in. diameter copper vent and the 3/4-in. diameter vacuum jacketed dump lines.

5. At LN_2 temperature the valves were checked for proper seating and operation by allowing LN_2 on one side of the valve and using a forepump on the other side. Under this condition a vacuum of about 7×10^{-2} mm of Hg was obtained, which is as good as was originally obtained under the previous contract NAS 3-4214.

6. The valve seats of the cold valves were again cleaned to remove any foreign material flushed into them by LN_2.

7. The valve package was then evacuated to remove any water and filled with gaseous nitrogen at a positive pressure of about 15 psig.

C. Connections from LH_2 Cryostat to Valve Package

These are the connections from the LH_2 cryostat to the valve package:

1. Five 1/2-in. diameter vent lines.

2. One 2-in. diameter vent line

3. One vacuum jacketed vent line which serves as the fill and dump line, and the annulus line which relieves the pressure between the inner and outer dewar in case of emergency. The vent lines were checked with a helium leak spectrometer prior to use. It was found that a number of pinhole leaks were present in one of the flexible vent lines. This is undoubtedly due to the many times this line was flexed when the cryostat was rotated during the previous contract period. Although only one vent line was found to have pinholes, the integrity of the other vent lines was suspect, therefore all of the 1/2-in. diameter vent lines will be replaced. This will be done prior to the LN_2 checkout on January 17, 1966.

D. "Bottle Farm"

The "bottle farm" is an array of nitrogen or helium gas bottles which are used for purging and for supplying the valve drivers. Two types of purging are required and therefore two systems are used. A third system is used for supplying the valve drives. One system acts as an emergency supply for quick dumping of the LH_2, heavy purging of the vent and dump lines, and transfer of the LH_2 within the cryostat. The other system supplies a small constant purge on the dump and vent lines and when necessary on the cryostat. Gaseous nitrogen is used for the LN_2 runs and gaseous helium for the LH_2 runs. The third system, which is used for the valve drivers, always uses gaseous nitrogen.

During the last contract period both the gaseous helium and nitrogen were supplied in cylinders. Since the gaseous helium is now Government furnished it will be supplied by a tube trailer and this will require replumbing the bottle farm since cylinders will still be used for the LN_2 checkouts, but the trailer will be used when the LH_2 runs are made. This replumbing will be completed prior to the LN_2 run of January 17, 1966.

E. Transfer Lines from the Valve Package to the LH_2 Supply Dewar

All of the vacuum-jacketed lines were checked out and the same vacuum existed as on the previous contract NAS 3-4214. These include some of the lines mentioned in II. C. and also a section of transfer line about 40 ft in length extending from the valve package to the outer edge of the linear accelerator building.

Early in the contract period problems arise with a 3/4-in. O. D. by 0.035-in. wall thickness vacuum jacketed transfer line which mated with the line mentioned above and was used to locate the storage dewar at a safe distance. This transfer line was about 50 ft long and was originally borrowed from Convair Division, General Dynamics. At the completion of the previous program we had requested that the lines be retained for our use on the new program. However, in the interim between the liquid hydrogen contracts, Convair Division moved from a temporary site to a permanent installation and these lines appear to have become inadvertently scrapped. Since the previously borrowed lines were not available, we borrowed from Convair Division the only other transfer lines which were available. These lines appeared to be in a poor condition but were taken to determine if they could be repaired. After examination it was determined that they were irreparable. As a result of the above a very thorough search was undertaken to locate 50 ft of acceptable transfer line.

We contacted Fort Worth Division, General Dynamics, Convair Division, and Liquid Carbonic Division, General Dynamics. Fort Worth had 1/2-in. transfer line and Liquid Carbonic Division had 30 ft of 1-1/4-in. flexible transfer line. Dr. John Liwosz (NASA Project Manager) searched NASA-Lewis Research Center and the Plumbrook installation without success. George Vila (General Dynamics Technical Representative at NASA-Lewis) has also searched NASA-Lewis and Plumbrook without success. He was able to find 66 ft of 3-in. diameter transfer line at Convair Division, which had not been previously used and was originally slated for the Centaur program. This line was available. However, the cost of the transfer line is essentially in the cost of the connections. The cost of 50 ft of stainless steel tubing, both the inner and outer members, is less than $400. Since the transfer line could be purchased for about $1, 500 this indicates that the cost of the connectors was about $1, 100. The female connector which must mate to the existing transfer line is a 3/4-in. Camco or NBS. To go to any section of transfer line such as the 30 ft of flexible line from Liquid Carbonic Division, requires two connectors at one end, i.e., a mate to the 3/4-in. Camco and the 1-1/4-in. transfer line. At the other end a 1-1/4-in. connector and a mating connector to the supply trailer would be needed, making a total of four connectors which would be required. This situation becomes more costly as the size of the connector increases as it would for the 3-in. diameter transfer line which could be borrowed from Convair Division. The 50 ft transfer line which could be purchased would also require only four connectors and would not impose the constraints on the equipment as would the larger or smaller line. The additional cost, if any, would be in the stainless steel tubing. On this basis, the transfer line was purchased with existing contract funds from Cryogenic Engineering Company.

The purchased transfer line is composed of two 25-ft sections. One end of one section connects with the 3/4-in. Camco and the other end is a 3/4-in. Marmon connector. The other section has a mate to the 3/4-in. Marmon connector and a 2-in. Air Force connector which mates with the Cosmodyne supply trailer to be furnished by Convair Division. However, it can also mate to the Beech supply trailer which is an alternate to the Cosmodyne and to a Linde supply dewar in case the trailer must be supplied by NASA WOO.

The 50 ft vacuum transfer line is expected to arrive on January 10, 1966.

F. Liquid Hydrogen Console

The liquid hydrogen console, which is remotely located in a room separate from the liquid hydrogen cryostat, is the control center for all valves. It also contains the liquid level indicators, the temperature readout of the Cu-Con thermocouples in the dewar, two remote monitoring TV systems, a sensitive pressure gage, hydrogen sniffers, remotely-operated valves for CO_2 purging of the enclosed area surrounding the dewar and a temperature readout of the Fe-Con thermocouples used to monitor fires in the area of the LH_2 cryostat. Since a portion of this system had been dismantled for use on other projects it was necessary to reinstall it, and to completely recheck all control circuitry for proper functioning. When the control circuitry was reinstated some modifications were found necessary and convenient. For instance, the location of the liquid hydrogen console was changed to isolate it during critical operations and the electrical components which comprise the liquid hydrogen console were rearranged to occupy two racks rather than one. These changes provide a more efficient operation of the facility and from the safety aspect, give the operator more complete control of all situations from his operating position.

G. New Support Structure for the Liquid Hydrogen Cryostat

The support structure for the liquid hydrogen (LH_2) cryostat used on the previous contract was not entirely satisfactory. It required complicated and tedious adjustments to align the probe tube and the flight path precollimator and constant checking between hydrogen runs was necessary to insure that alignment had been maintained, and it was extremely sensitive to external contacts such as bumping or jarring, and difficult to translate. The older support structure was composed of two parts: a single column with a cantilever arm support structure supplied by Cryenco, who also built the LH_2 cryostat, and the table upon which this support structure was placed to give the cryostat mobility and the necessary vertical and lateral movements for alignment with the flight path system.

Early in this contract period a new support structure was designed, then later built and tested. This support system is shown in Fig. 1. As can be seen the support structure and table have been incorporated into a single unit. Furthermore, two crossmembers instead of one have been used for the structure making the structure sturdier and less susceptible to deflections under load. Vertical movement is provided by sliding wedges at the top of the support structure; they are shown in more detail in Fig. 2. Lateral movement is provided by a manually operated lead screw drive which is shown in Fig. 3. Mobility is obtained by a removable screw-on wheeled carriage which can be seen in Figs. 1 and 4. During experiments the support structure is bolted to the floor. This new method of supporting the cryostat has proven to be more mobile, sturdier, easier to align, and to keep in alignment.

Prior to actual use the new support structure and carriage were subjected to a load test as an additional safety measure. A 4000-lb load was used as a mockup of the hydrogen cryostat and served as a test of the integrity of the structure. This was twice the anticipated load of 2000 lbs which the cryostat weighs when it is filled with liquid nitrogen.

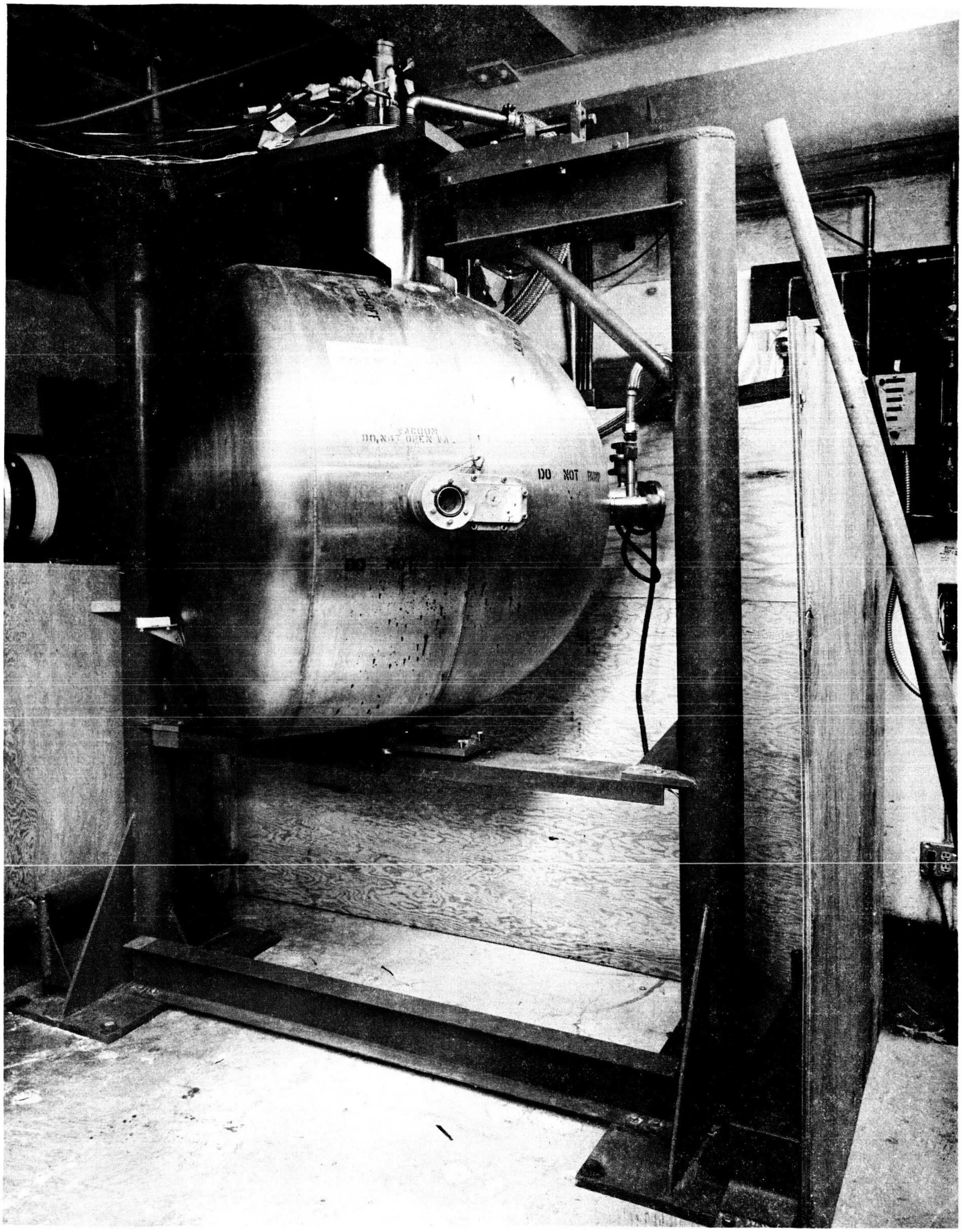

Fig. 1--Liquid hydrogen cryostat support system

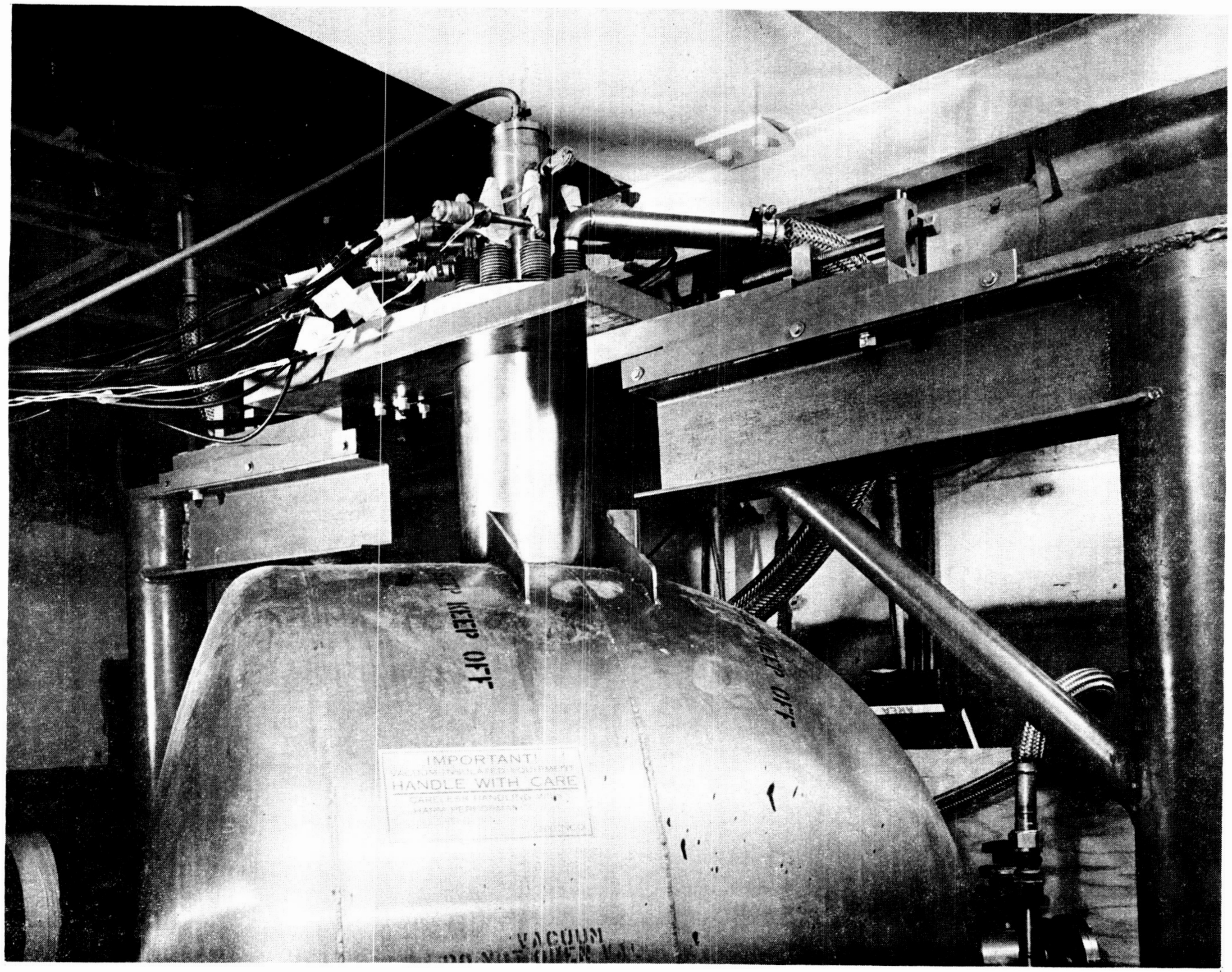

Fig. 2--Details of sliding wedges for vertical movement of liquid hydrogen cryostat

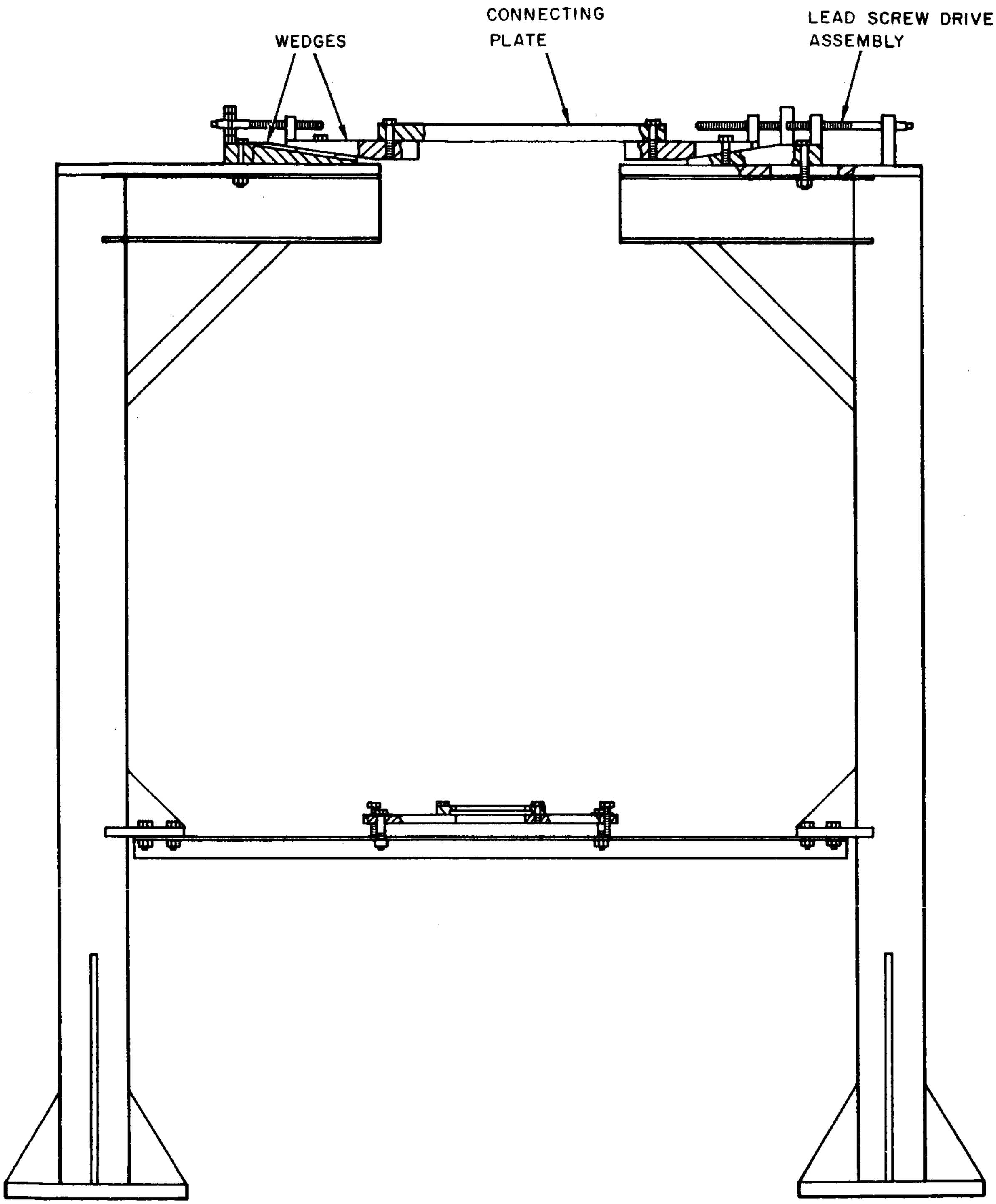

Fig. 3--Liquid hydrogen support structure. Lateral movement is provided by the lead screw drive assembly.

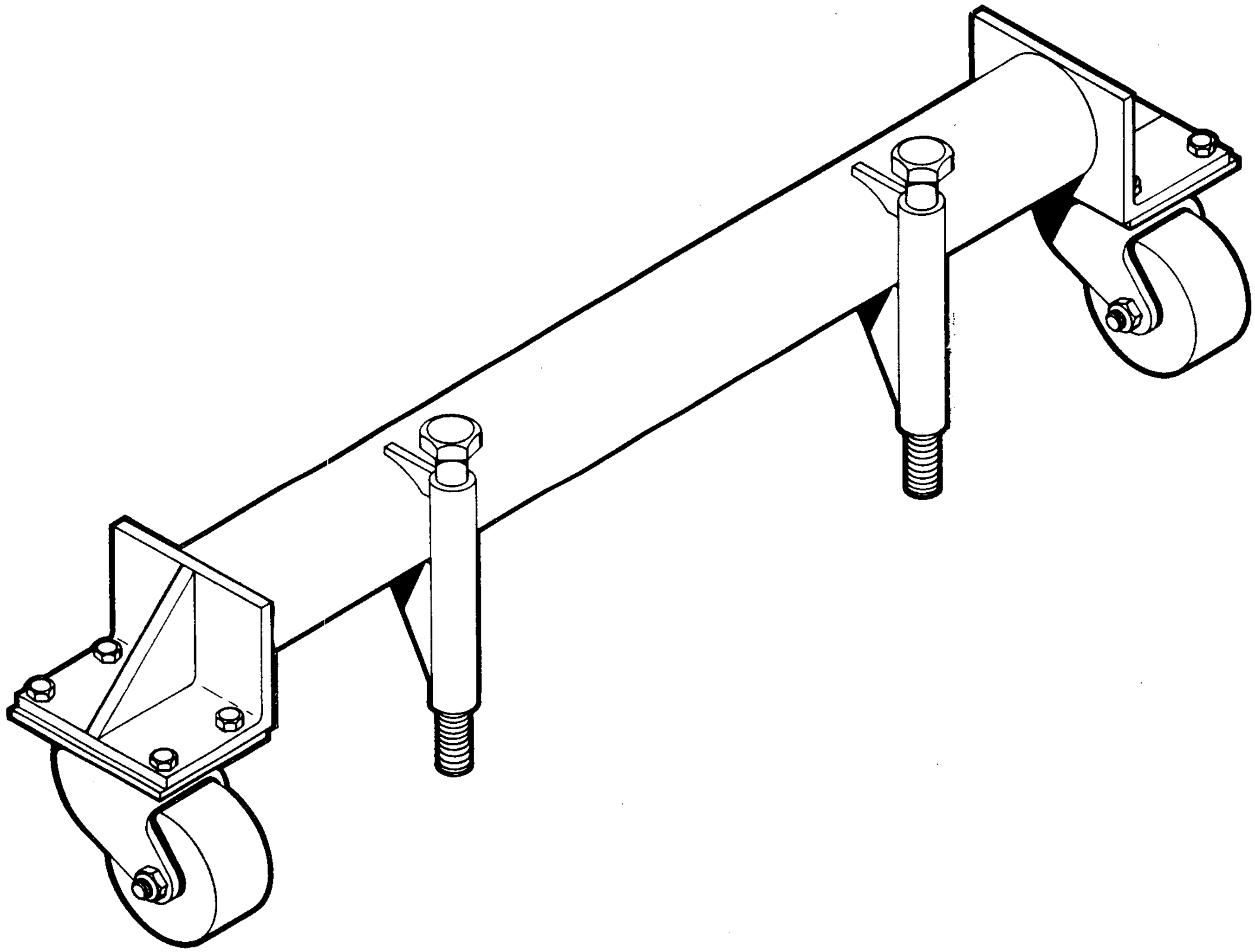

Fig. 4--Screw-on wheeled carriage for moving the liquid hydrogen cryostat and support system.

The wedge devices which are used to raise, lower, and move the cryostat horizontally were tested with a 1000-lb load which is slightly more than the empty cryostat. These adjustments are made when the dewar is empty. The carriage which raises the entire support structure with the cryostat and gives mobility to the system was tested with 1000 lbs. All of these tests were successful and proved the versatility and simplicity of this design over the original design. The displacement of the "I" beam support at the edge nearest the support point of the cryostat was 0.028-in. with the 1000-lb load and this weight is slightly more than the weight of the cryostat filled with liquid hydrogen.

III. DELIVERY SCHEDULE AND SUPPLY OF LN_2 AND LH_2 BY CONVAIR DIVISION, GENERAL DYNAMICS

During the last contract period, much difficulty was experienced in obtaining LN_2 and LH_2 from Convair Division. One of the main problems was the lack of contact or communication with someone who could be responsible for seeing that the GFP (Government Furnished Product) LN_2 or LH_2 would be delivered as scheduled. For the present contract, LN_2, LH_2 and gaseous helium are all GFP. In order to correct this situation Dr. Liwosz, John Danicic (NASA, Contract Specialist), and technical and contract people from General Atomic met with representatives from Convair Division. This meeting resulted in a written document agreed upon and signed by the above which details, among other things, delivery dates and conditions under which these dates may be changed.

IV. HYDROGEN SNIFFERS

A hydrogen sniffer is an electronic device which warns that hydrogen is present at some percent of LEL (lower explosive limit). The hydrogen sniffers forewarn that leaks are present in the system before hydrogen concentration is at the explosive level. On the last contract we obtained on loan a demonstration model hydrogen sniffer system from General Monitors, Inc., for use during the actual liquid hydrogen measurements. They were used on a trial bases and proved to be quite satisfactory on a high radiation field such as is found at the linear accelerator. This hydrogen sniffer system used bifilar platinum wires for the sensing element. Originally, we had planned to borrow the hydrogen sniffers from Fort Worth Division but they were needed for a program at Fort Worth Division.

General Monitors, Inc., now has a commercial unit at a lower and competitive price, which uses a thermistor coated with a catalyst in a bridge circuit. The preamplifier can be remotely located up to 2000 ft. We obtained a demonstration hydrogen sniffer system from General Monitors, Inc., to determine if the thermistor in the sensing head could withstand the high radiation fields attendant with an electron linear accelerator. These thermistor sensors have been used successfully in fairly high radiation fields around a reactor at Fort Worth Division. The test involved placing the probe in a radiation field (shielded by 4-in. of lead) in which the integrated dose would be equal to the total of the two LH_2 experiments. After this test the calibration of the sensory probe was difficult and erratic. This was traced to the sensing element. Since it was not certain whether the failure of the sensory element was singular, it was decided to irradiate two such sensing elements. Since these irradiations are parasitic, it has not been possible as of this date to obtain a integrated dose greater than 1/4 of the amount expected for the two LH_2 experiments. Since time is running out, two approaches remain: (a) use the thermistor sensor outside the radiation areas and use bifilar platinum sensors for use in the high radiation areas, or (b) buy two spare thermistor sensor heads for the two sensors which will be located in the high radiation field and use them as backups in the event of failure.

V. WATER-COOLED FAST NEUTRON SOURCE

A water-cooled fast neutron source has been constructed to replace the air-cooled isotropic fast neutron source used in the previous program. The air-cooled source was limited in its heat dissipation capability and hence fast neutron production. The water-cooled source will be of the same design as the air-cooled source except that a jacket will allow a thin layer of water to flow around the depleted uranium sphere and also in front of the surface which the electron beam strikes. The water jacket assembly has been completed but final assembly is pending on the arrival of the 3-in. diameter uranium sphere. This sphere will have an electroplated undercoating of copper and an overplating of nickel similar to the air-cooled source. The manufacturer had some difficulties in coating the surface which the electron beam strikes; the first source was rejected for this reason. This surface is at the bottom of a 1-in. diameter cylinder which extends to within 0.33-in. of the center of the sphere and is very critical. This difficulty was also encountered with the air-cooled target and was an important factor in restricting the power level which could be used with the air-cooled source. This problem has been solved by the manufacturer by making the sphere from a forged uranium ingot. This has eliminated the porosity found in the cast uranium ingot. The source is expected to arrive the first week in January. The isotropy of this source will be checked in January for comparison with the air-cooled target used on the previous contract.

VI. THERMAL NEUTRON MEASUREMENTS

The first set of measurements will be made at thermal energies in LH_2. The flight path collimation system was set up during the first contract period to cover the entire energy range from thermal to fast, but only at fast neutron energies had any extensive measurements been made to prove the effectiveness of the collimation. The leakage spectrum from a standard geometry was measured to determine the effectiveness of the collimation system for thermal neutrons. The standard geometry consists of a 12 in. by 12 in. by 2 in. 1% borated polyethylene assembly with a 4 in. thick lead wall to distribute the fast neutron source which is placed just off the axis of the assembly. The spectrum from this standard geometry is well known and has been used for many years by the General Atomic neutron thermalization group as a check on its overall system which includes their precollimator, flight path collimation, and detector. The precollimator, flight path collimation, detector, and detector positioning and housing were the same as were used for the fast neutron measurements. The distance from the end of the precollimator to the surface of the standard geometry assembly was 28-in.; this is the same distance as that used for the fast neutron measurements and is expected to be used for the thermal measurements in LH_2. Therefore, the entire geometry is an exact mockup of the thermal measurements to be performed in the LH_2. When leakage spectrum data are reduced it will be possible to determine if the flight path system is adequate for use with the LH_2 measurements.

VII. FIRST CHECKOUT OF LIQUID HYDROGEN FACILITY USING LIQUID NITROGEN

As mentioned previously a thorough checkout of each component of the liquid hydrogen facility has been made. To check the LH_2 facility liquid nitrogen (LN_2), which is the most logical cryogenic fluid nearest to LH_2 temperature, was used.

The first LN_2 checkout was made on December 6, 1965. This checkout proved the entire system was, in general, functioning properly although some minor problems were encountered. A leak in the valve drive system was found and repaired. The teflon hose seal on the fill-dump line bayonet had apparently suffered radiation damage and swollen such that it was not mating properly with the female portion of the bayonet. One of the liquid level lights did not indicate the level properly.

There are two more scheduled LN_2 checkouts prior to the first LH_2 experiment. The operation of the LH_2 facility is complex and potentially dangerous; these checkouts serve to retrain and familiarize the personnel in the operation of this facility as well as to point out the numerous small problems which arise.

VIII. CHANGE OF SCHEDULE

The third LN_2 checkout originally slated for February 4, 1966 has been rescheduled for February 14, 1966. The third checkout was originally scheduled for the week during which the linear accelerator would be shut down for upgrading. Since this shutdown has been changed, the LN_2 checkout was rescheduled for the week before the actual LH_2 measurements.

The first LH_2 measurement has been rescheduled for February 20, 1966, instead of February 14, 1966. Delivery of the gaseous helium has been changed to February 15, 1966, so that it will arrive prior to the LH_2.

IX. THEORETICAL CALCULATIONS IN THE FAST NEUTRON REGION

Theoretical calculations have been made in the fast neutron region which extends from 15 to 0.5 MeV. These calculations were made with a modified form of GAPLSN[1] which is called GGSN; it requires less computer time to run since only down-scattering is considered.

The liquid hydrogen cryostat is a two-dimensional geometry. It essentially represents a cylindrical container of LH_2 with an isotropic fission source at one end. The experimental geometry is shown in Fig. 5. GGSN is a one-dimensional S_n transport theory code. Within the framework of GGSN, the geometry of the LH_2 cryostat can be represented either as a sphere or slab. Both approaches have been used and the results of these calculations are discussed below.

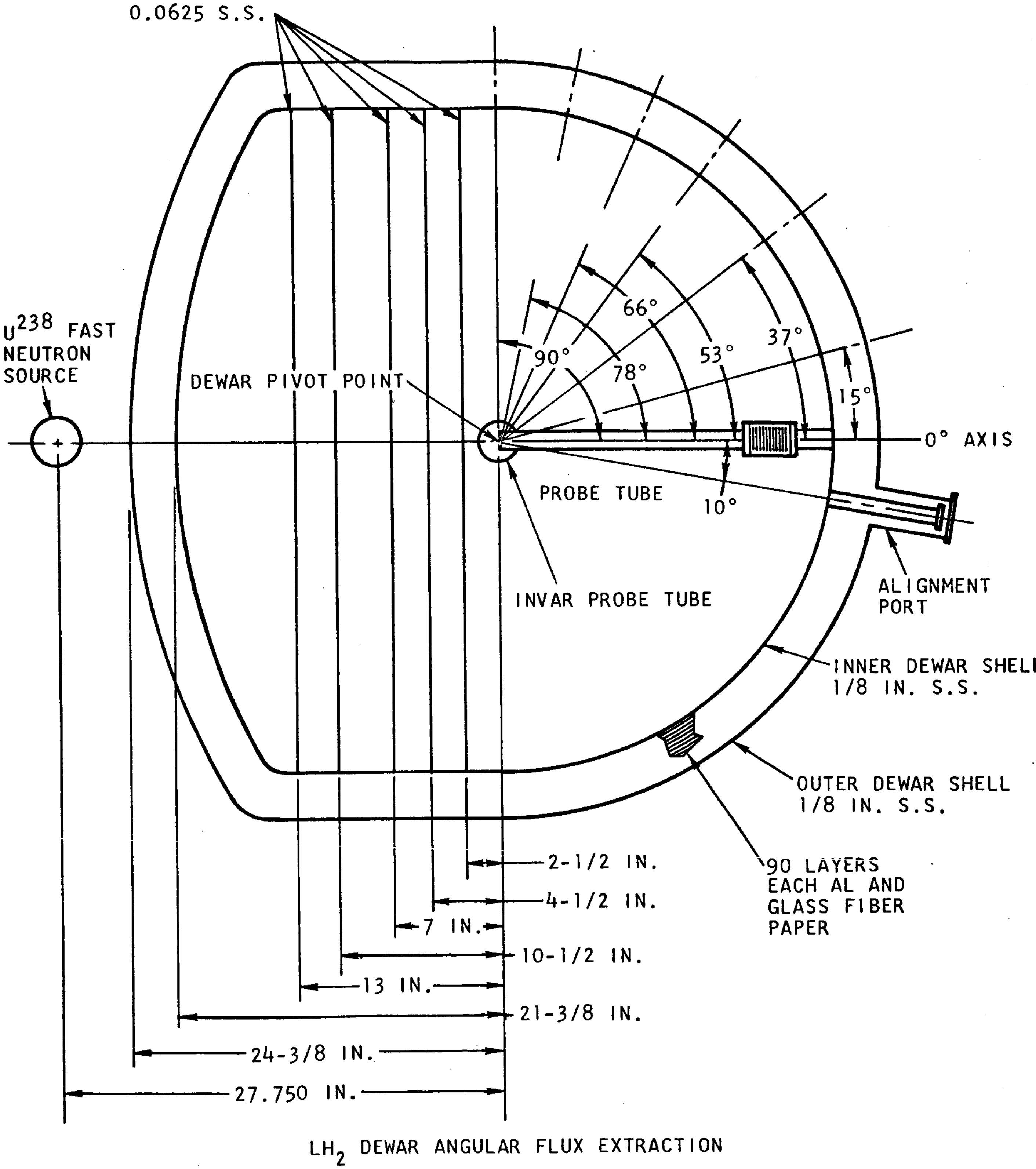

Fig. 5--LH_2 dewar baffle spacings

A. Spherical Geometry

A volume source was used for the spherical geometry calculations. The uranium in the fast neutron source was not included in the calculations. Instead, the source was approximated by an isotropic emitter with intensity uniformly distributed over the target sphere of radius 3.81 cm. The input source was the measured hemisphere - integrated source spectrum of run 1, 6-28-65, which was measured under another program. The energy-group structure and Q, the group source intensities, are listed in Table I. Since the spectrum was not measured below 0.5 MeV the source was arbitrarily set to zero; group 10 is simply a catch-all for degraded neutrons. The energy groups were chosen to adequately represent the flux spectrum and to allow correct calculation of neutron transport at deep penetrations in liquid hydrogen.

Experience with similar calculations has shown that the off-zero degree flux is relatively insensitive to the angular distribution of the source neutrons. The flux at 0^{o} does depend on the details of the source description; further work on the source characteristics which is now in progress under another program will provide the information required for 0^{o} flux calculations if these should be desired later.

Group cross sections for hydrogen and stainless steel were obtained from the GAM-II code.[2] Only P_0 cross sections were available or needed for the small amount of stainless steel involved, but P_3 cross sections were calculated for hydrogen. Experience with neutron transport calculations in CH_2 have shown that a P_1 approximation of the hydrogen elastic scattering distribution is inadequate. The spectrum for group averaging was obtained from a B_3 calculation ($B = 10^{-10} cm^{-1}$) in GAM-II, with a U^{235} fission source spectrum assumed as this is sufficiently accurate for the purpose. The hydrogen macroscopic cross section ($n_H = 0.04264 \times 10^{24}$ cm^{-3}) was obtained as well as the stainless steel microscopic cross sections averaged over the flux in pure hydrogen

TABLE I

GROUP SOURCE INTENSITY

Group	E (MeV)	Q (n/cm^3sec)
1	14.92-10.00	1.5446
2	10.00- 7.41	6.6871
3	7.41- 5.49	17.3894
4	5.49- 4.07	28,0207
5	4.07- 3.01	38.3966
6	3.01- 2.02	65.0463
7	2.02- 1.00	148.6630
8	1.00- 0.743	66.8939
9	0.743-0.550	58.8153
10	0.550-0.41 eV	0.0000

In the transport calculation, an atom density of $0.0843 \times 10^{24}\ cm^{-3}$ was used for the stainless steel.

A preliminary calculation in spherical geometry was carried out with an S_8 angular mesh and 124 spatial intervals with a liquid hydrogen thickness of 13 inches. It was felt, however, that an S_{16} angular mesh should be used to correspond more exactly with the angles in the experiment, and to represent the forward-peak nature of the angular flux more exactly. Since the fineness of the spatial mesh has to be consistent with the angular mesh and the mean free path, and since many intervals also have to be included between the source and the liquid hydrogen, the storage capacity of the computer was severely taxed.

The S_{16} calculation of 11-5-65 was performed for the geometry shown in Fig. 6. This approximates the geometry for the measurement of the spectrum at a liquid hydrogen thickness of 4.5-in., but there is no material past the 4.5-in. depth. The source region and region between the source and first stainless steel baffle was taken as gaseous hydrogen (density 1.57% of the liquid hydrogen density). The calculated angular flux spectra are plotted in Fig. 7.

A similar calculation was made for a liquid hydrogen thickness of 7 inches. The geometry is shown in Fig. 8 and the calculated spectra in Fig. 9.

Previous experience had indicated that the angular flux from 0^{o}-60^{o} would be quite insensitive to whether or not additional material was present beyond the 70.485-cm radius, which corresponds to the position of the probe tube or the sampling point of the neutron spectrum in the experiment. To check this, the calculation was repeated on 11-9-65 with the geometry corresponding to the 4.5-in. thickness (Fig. 6) except that additional liquid hydrogen was included, to an outside radius of 88.265 cm. Also, since we suspected the stainless steel baffles had little influence on the spectrum, they were omitted. In Fig.10 the 4.5-in.

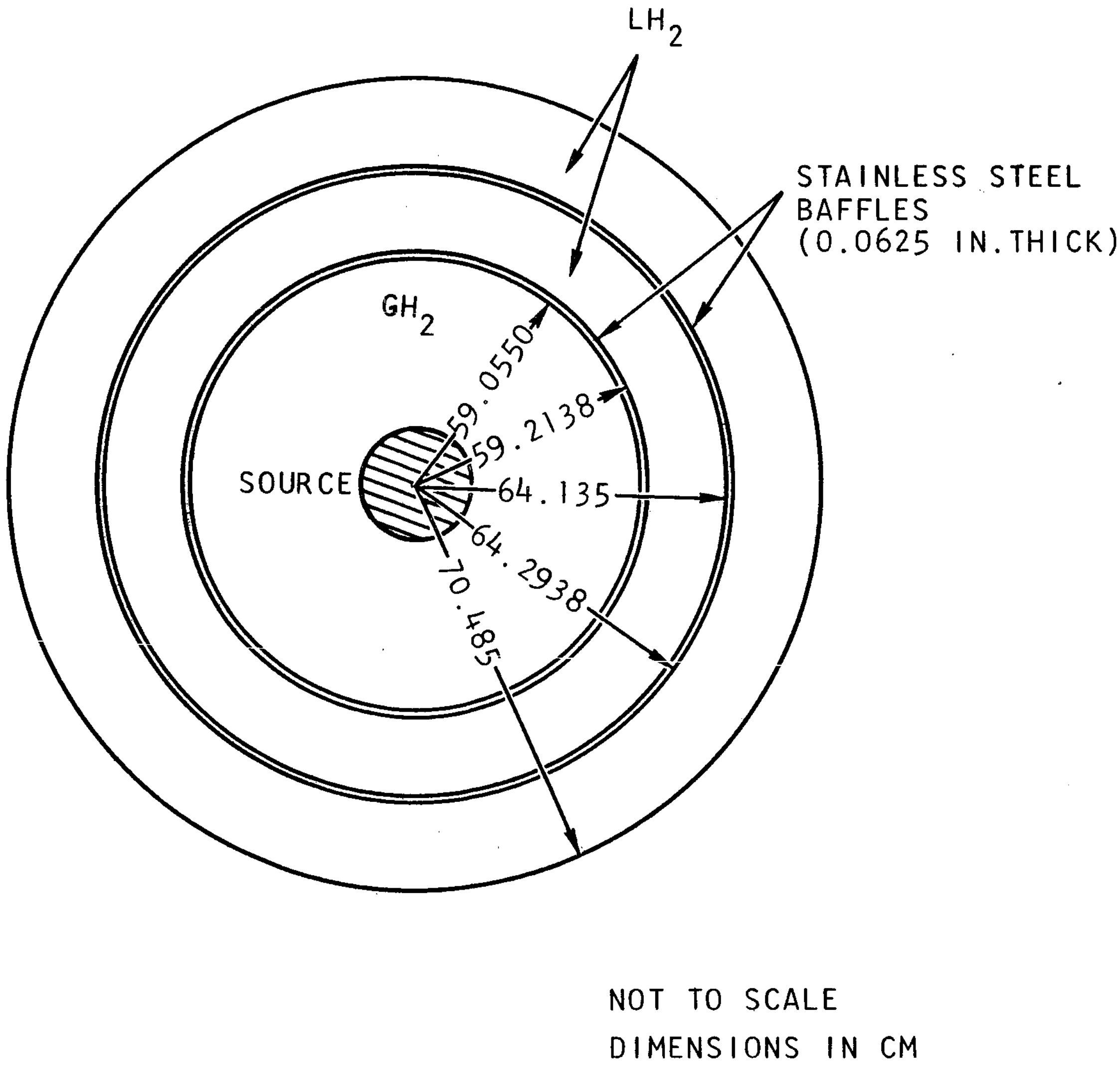

Fig. 6--Geometry for 4.5-in. GGSN 11-5-65.

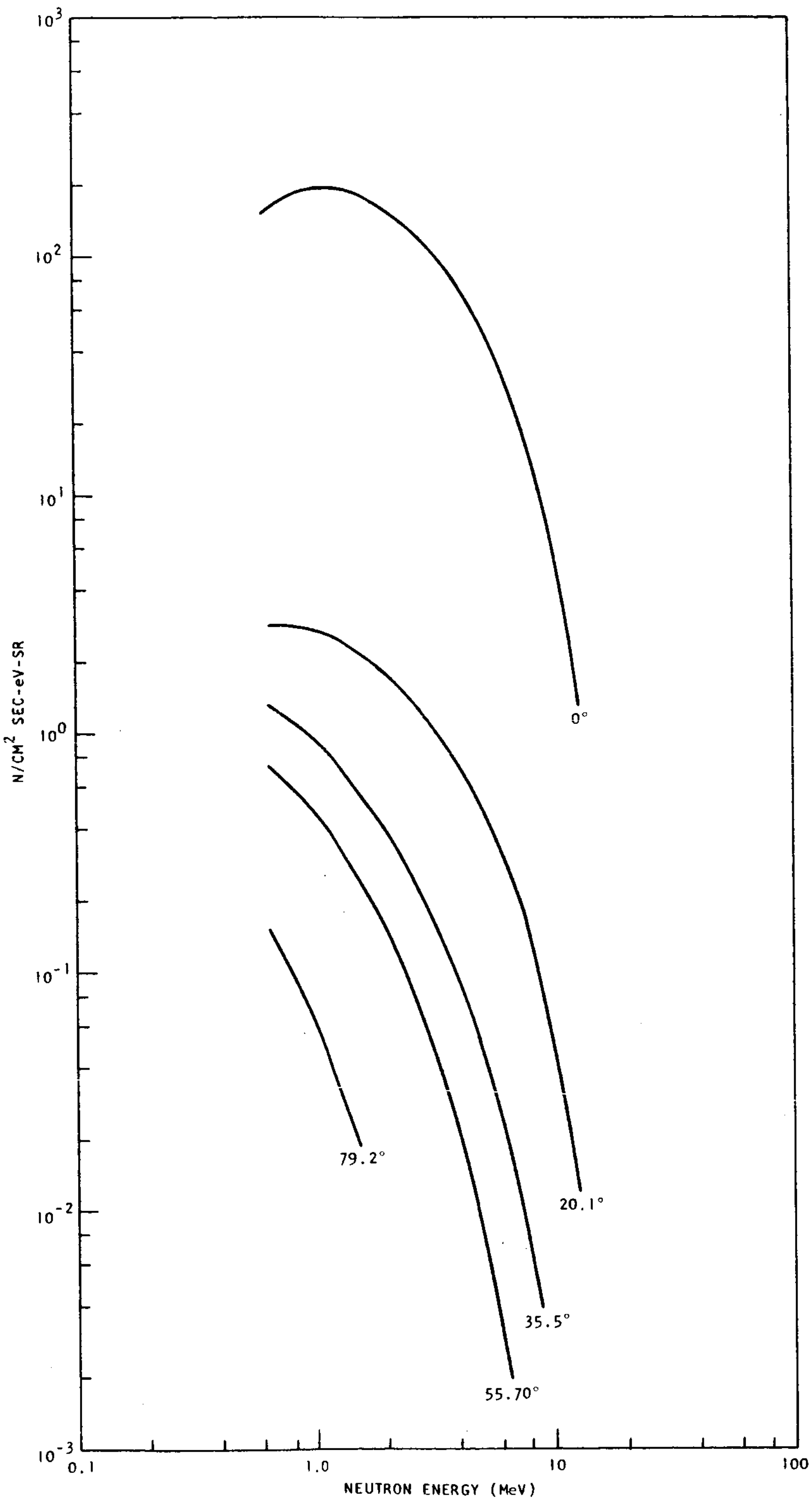

Fig. 7--LH_2 spherical GGSN, 4.5-in., 11-5-65, P_3S_{16}.

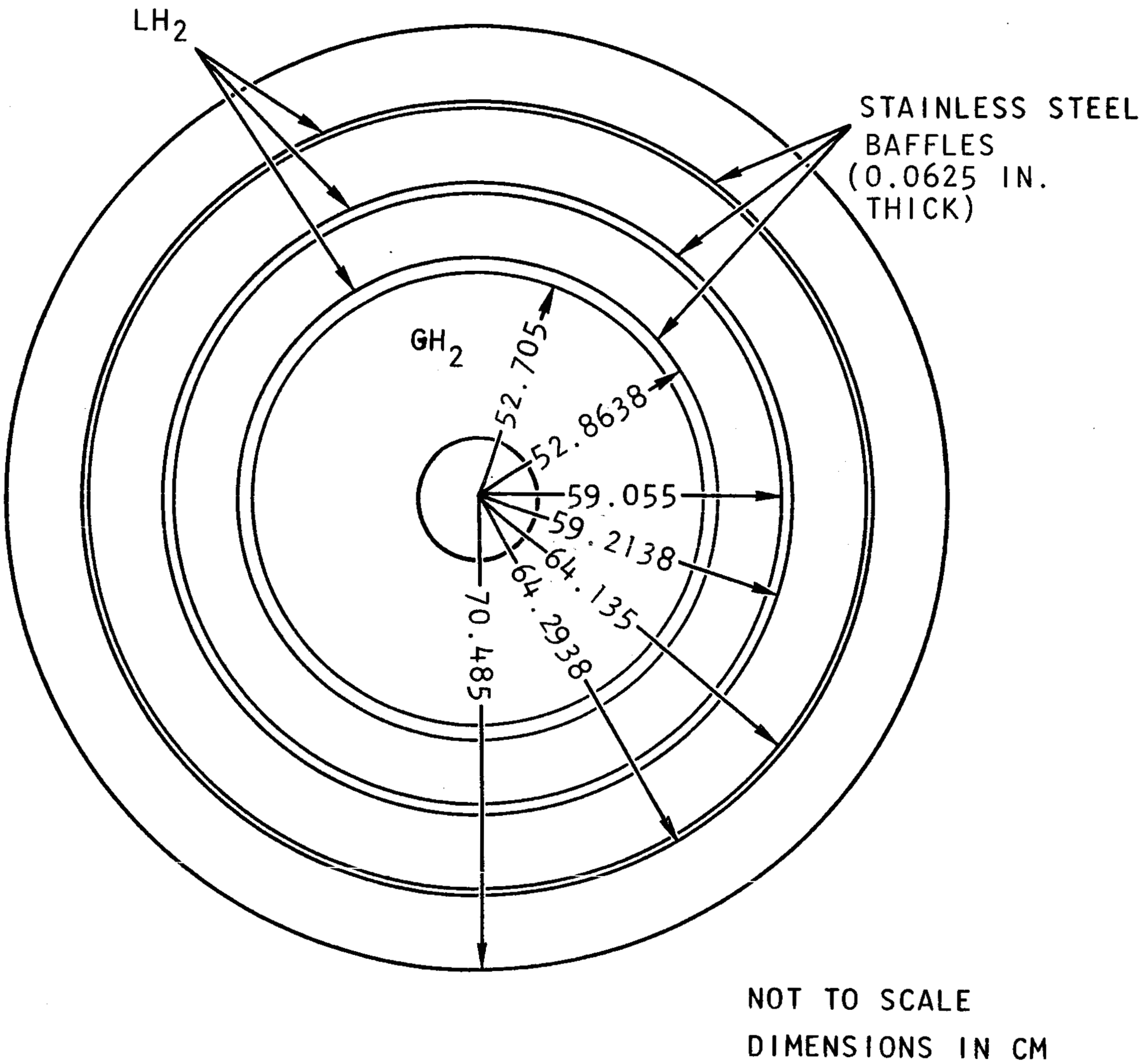

Fig. 8--Geometry for 7-in. GGSN 11-5-65.

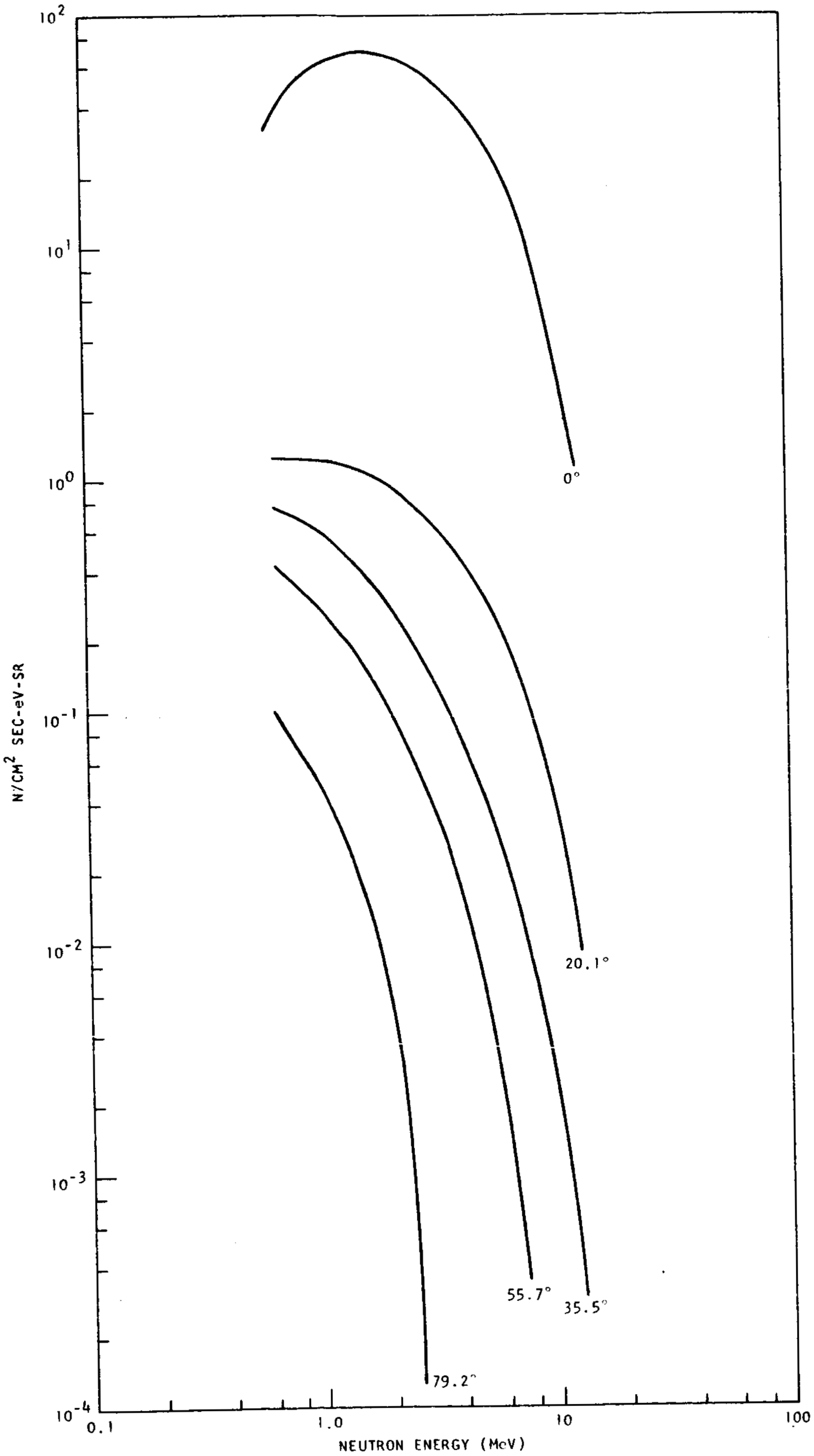

Fig. 9--LH_2 spherical GGSN, 7-in., 11-5-65, P_3S_{16}.

calculation of 11-9-65 is compared with the 4.5-in. calculation with baffles but no hydrogen back-scattering also plotted in Fig. 7. Differences are small and are probably due to the different amount of hydrogen behind the measurement point. Agreement between the 11-5-65 and 11-9-65 calculations (not shown here) is also very good at a penetration depth of 7 inches.

Since the source spectrum used to derive the source intensity for the calculation was monitored in a different way than the spectra measured in the liquid hydrogen, a normalizing factor must be found to relate calculated magnitude to experiment. This problem is still under study; hopefully we can use the target spectrum measured at 0° through the empty cryostat, with proper correction for collimator size and detector efficiency. Meanwhile, we can compare shapes and angular distributions by arbitrarily normalizing at one energy and angle.

Measurements and the 11-9-65 GGSN calculations mentioned above for the 4.5-in. penetration are compared in Fig. 11, normalized at 37° (to 35.5°) and 5 MeV. Agreement in shape is not good, although the rapid rise of measured spectra at low energies may be due to an incorrect bias determination, which can be corrected later. Even so, the angular distribution is apparently not calculated accurately. Since the discrepancy may very well be due to the approximation of the experimental geometry by a sphere in the calculation, we decided to go to the other extreme geometry available to us in GGSN, namely an infinite slab.

B. Slab Geometry

In one-dimensional slab geometry, the lateral extent is assumed infinite, a very good approximation of the experimental situation. An advantage of the slab is that a surface source can be specified, avoiding the need for space points in the region between source and shield

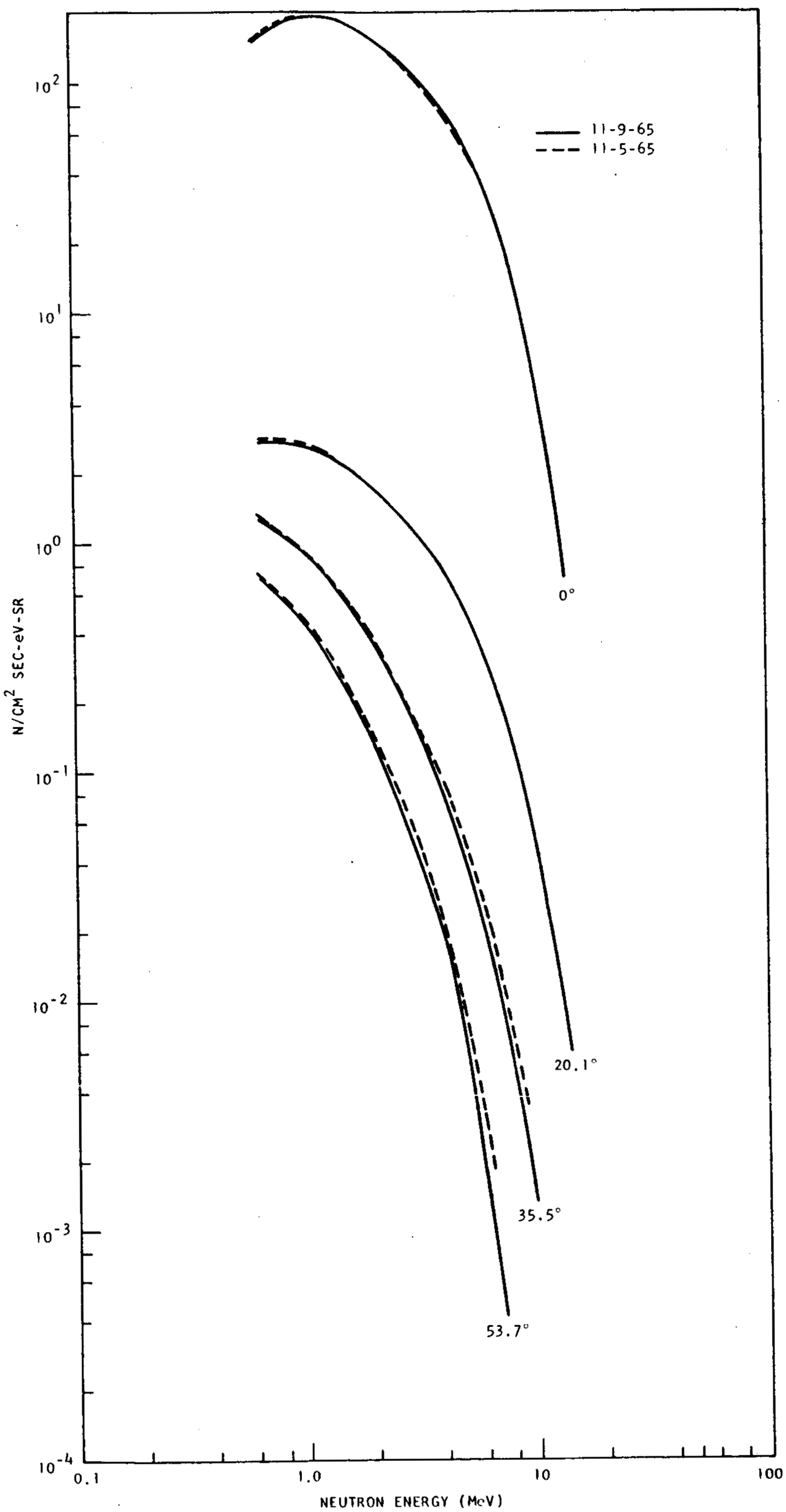

Fig.10--LH_2 spherical GGSN, 4.5-in., 11-9-65, P_3S_{16}.

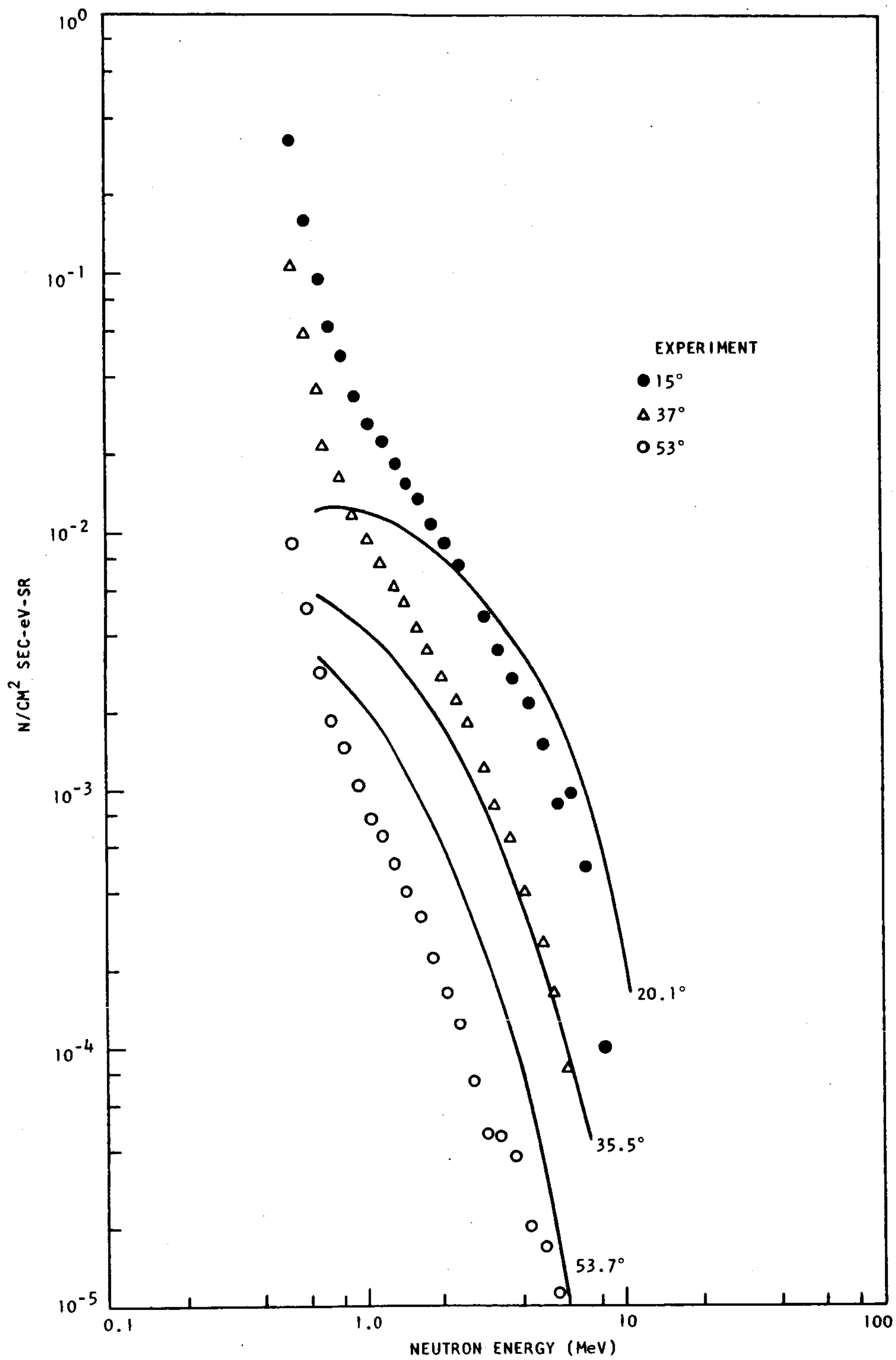

Fig. 11--Comparison of measurements and spherical calculations of 11-9-65 at 4.5-in.

(in the spherical GGSN a surface source can be specified only on the outer radius). However, the true angular distribution of the neutrons incident in the experiment cannot be reproduced exactly in the one-dimensional calculation (no radial dependence of angle or intensity). We do have a special version of GGSN for slab calculations which allows us to specify the angular mesh in the input, rather than being limited to equal intervals as in the spherical geometry. Furthermore, the angular distribution of the surface source can be limited to the first interval near zero, thus allowing us to specify normal incidence, plus or minus a range of angles about normal incidence corresponding to the width of the first angular interval. The same source spectrum shape was used as in the spherical calculations. Absolute normalization of source intensity to that of the spherical calculations, or experiment, has not been carried out as yet.

The angular mesh boundaries (in $\mu = \cos \theta$) for the GGSN slab calculation of 11-13-65, and the group surface source intensity, Q_s, are given in Table II. The source is assumed to be on the right hand side of the slab, so the angles of interest are for negative μ. The stainless steel baffles were omitted. The angular flux spectra calculated at nominal 4.5-in. penetration (less two baffles of 0.625 in. each or 4.375-in. of liquid hydrogen) are plotted in Fig. 12. The curves are seen to lie much closer together than in the spherical case, and closer than experiment. The source angular interval is $\mu = 1.000$ to 0.9999, or $0^{o} \pm 51'$. The spectra at the nominal 7-in. penetration (less three baffles of .0625 in. each or a liquid hydrogen thickness of 6.8125 in.) are given in Fig. 13. The total slab thickness was 33.0 cm.

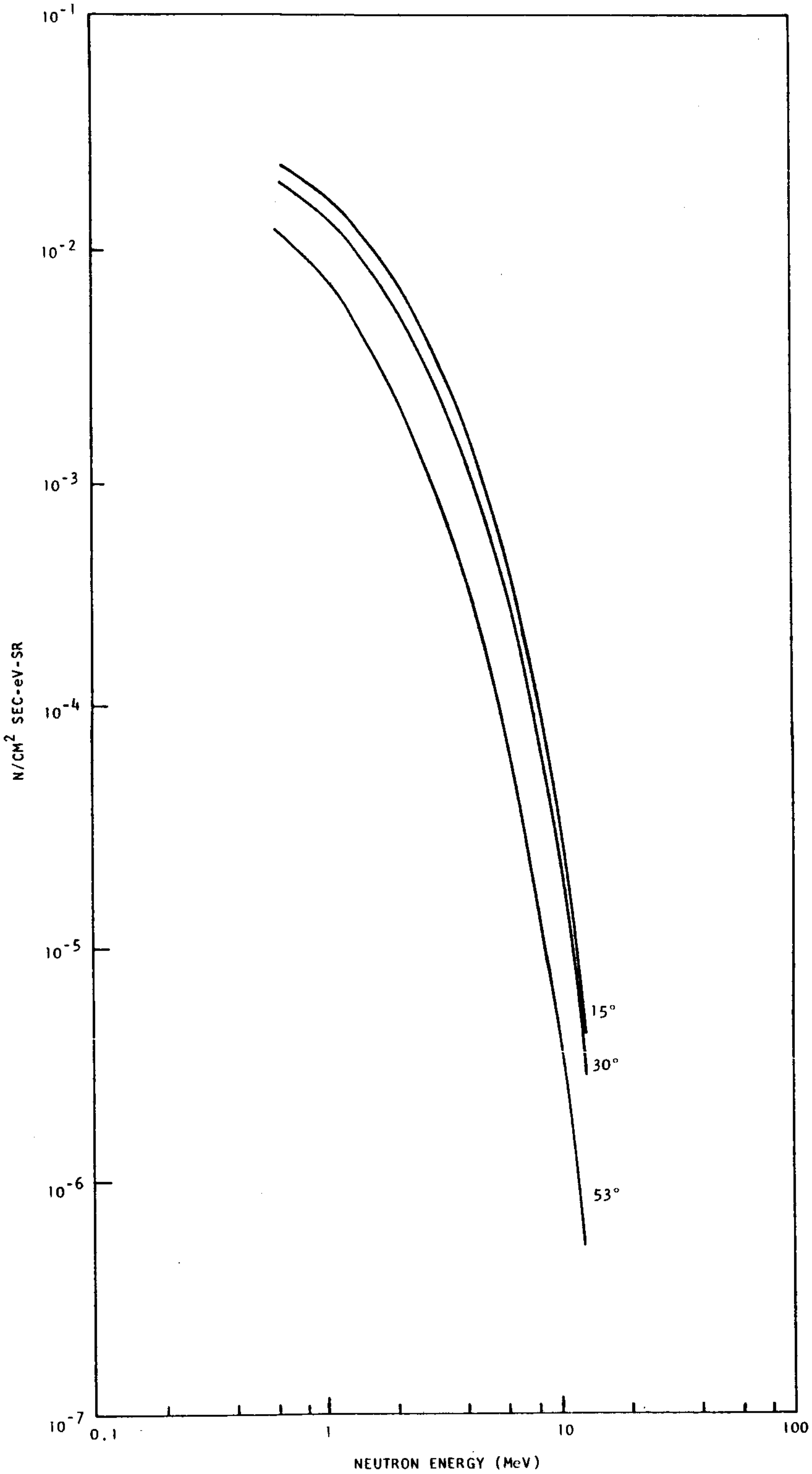

Fig. 12--LH_2 slab, GGSN, 4.5-in., 11-13-65.

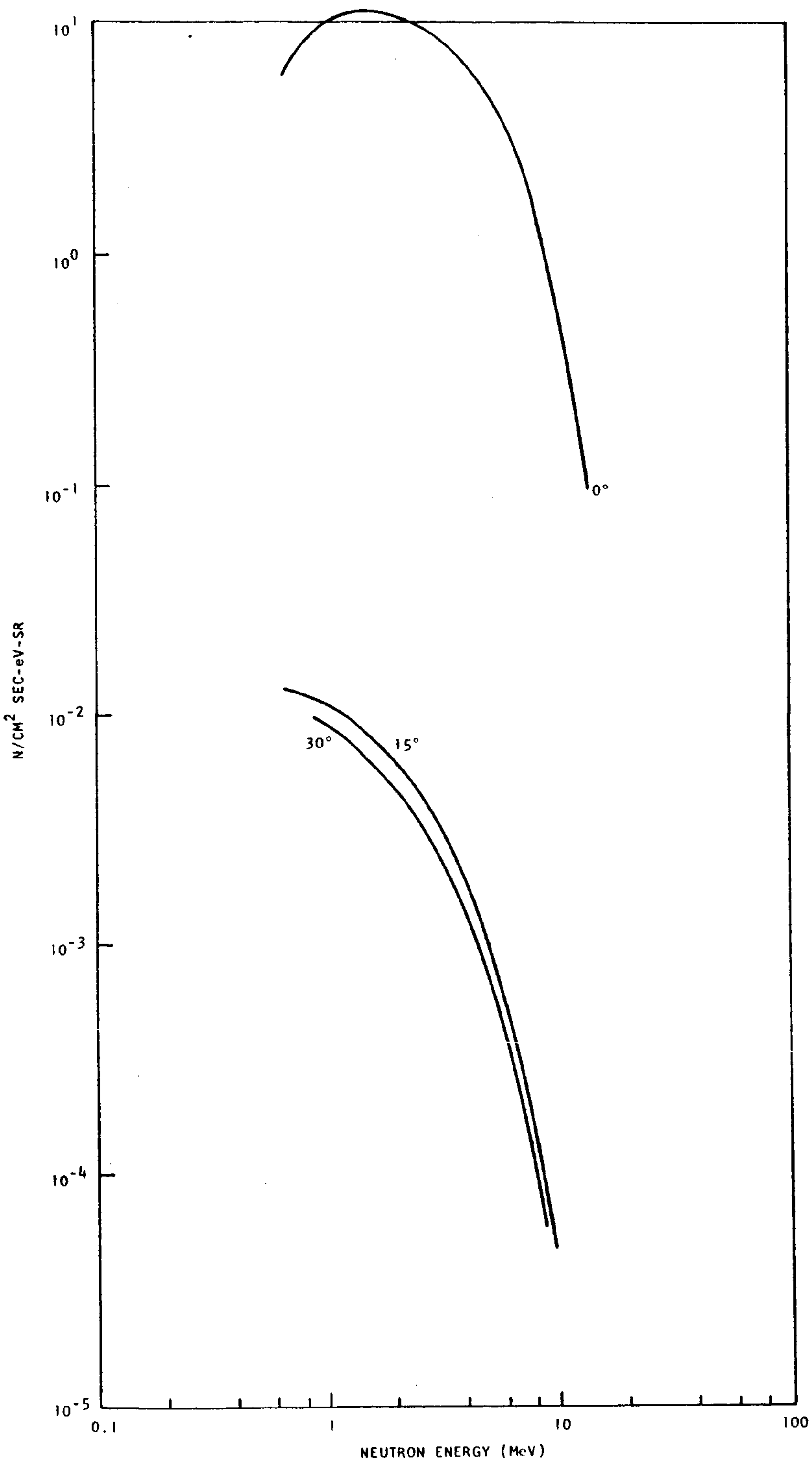

Fig. 13.--LH_2 slab, GGSN, 7-in., 11-13-65.

TABLE II

SLAB GGSN, 11-13-65

μ bounds

-1.00000 to -0.9999	0.000 to 0.125
-0.9999 to -0.9788	0.125 to 0.250
-0.9788 to -0.9530	0.250 to 0.375
-0.9530 to -0.7782	0.375 to 0.500
-0.7782 to -0.4254	0.500 to 0.625
-0.4254 to -0.3880	0.625 to 0.750
-0.3880 to 0.0000	0.750 to 0.875
	0.875 to 1.000

Group	Q_s
1	1.5446
2	6.6871
3	17.3894
4	28, 0207
5	38.5966
6	64.0463
7	148.6630
8	66.8939
9	58.8153
10	0.0000

The angular intervals specified in Table II are considerably larger than the angular resolution of the experiment at other than zero-degrees. The flux calculated by the S_n method is the average over the angular interval. To see if this had any effect on the results, the calculation was repeated on 12-13-65 with the angular interval boundaries of Table III, which include intervals at the experimental resolution (the first angular interval is smaller than for the 11-13-65 calculation but this was inadvertent).

TABLE III

SLAB GGSN, 12-13-65, NARROW SOURCE

μ bounds	
-1.00000 to -0.99999	0.000 to 0.125
-0.99999 to -0.97437	0.125 to 0.250
-0.97437 to -0.95630	0.250 to 0.375
-0.95630 to -0.81915	0.375 to 0.500
-0.81915 to -0.77715	0.500 to 0.625
-0.77715 to -0.62932	0.625 to 0.750
-0.62932 to -0.57358	0.750 to 0.875
-0.57358 to 0.00000	0.875 to 1.000

Calculated spectra for these intervals are quite close to those in Figs. 12 and 13 indicating the angular mesh to be sufficiently good and the results not very sensitive to the angular resolution.

Finally, the influence of the angle of incidence of the neutrons was investigated by increasing the width of the first angular interval to $\mu = -0.97437$ ($0^{\circ} \pm 13^{\circ}$). The results at nominal 4.5-in. penetration are plotted in Fig. 14 and compared with the results for the narrow source angular range of Table III. Since the intensity of the source was not

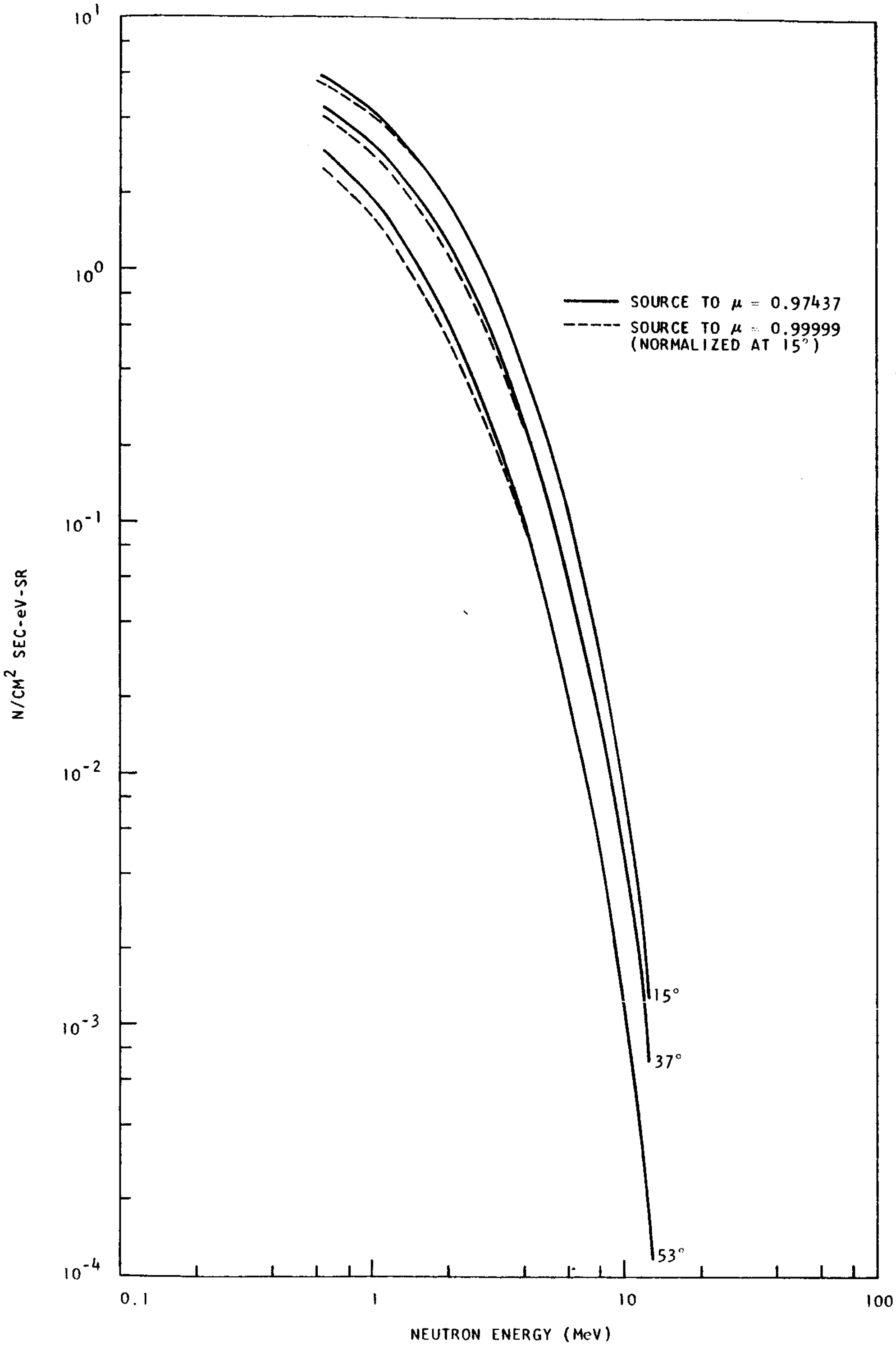

Fig. 14--LH_2 slab variable angle, 4.5-in., 12-13-65.

changed to compensate for the different width, the narrow-angle-source spectra are normalized in magnitude at 15° to the wide-angle-source spectra, to compare shapes and angular distributions. Evidently the spectra at 4.5 in. are not very sensitive to the angle of incidence.

Comparison of experiment and the slab calculations shows that the angular distribution is considerably more forward peaked in the calculations than in the measurements. This is seen in Fig. 15 where the 15° and 37° measurements at 7 in. are compared with the 11-13-65 GGSN slab calculations (from Fig. 13), normalized at 15° and 5 MeV.

Our conclusion is that neither the sphere or the slab calculations are able to represent the geometry of the experiment, and two-dimensional calculations are called for.

X. WORK PLANNED FOR THE NEXT MONTHLY REPORT PERIOD

In the next monthly report period the LH_2 cryostat and support structure will be moved into position in front of the flight path system. A sheet metal building will be built around the LH_2 facility and will serve to minimize the volume in which an air change must take place and to localize any hydrogen which might possibly escape. Reinstallation of the safety devices will be initiated. Estimated date of completion of the installation is February 14, 1966. Theoretical calculations of thermal neutron spectra in LH_2 will be made using GAPLSN. Time-of-flight measurements will be made on the water-cooled 3-in. diameter depleted uranium source to determine if the isotropy and spectra are the same as for the air-cooled source used on the previous contract.

A number of mechanical devices will be designed, built, installed, and checked prior to the initial LH_2 run scheduled at this time for February 20, 1966. These items are: the source support, the remotely operated background plug for the thermal neutron measurements, and the holder for the aluminum slug used to monitor the runs. The platform for working around the top of the LH_2 cryostat and support structure must be modified and installed. The water jacket must be mounted around the uranium source.

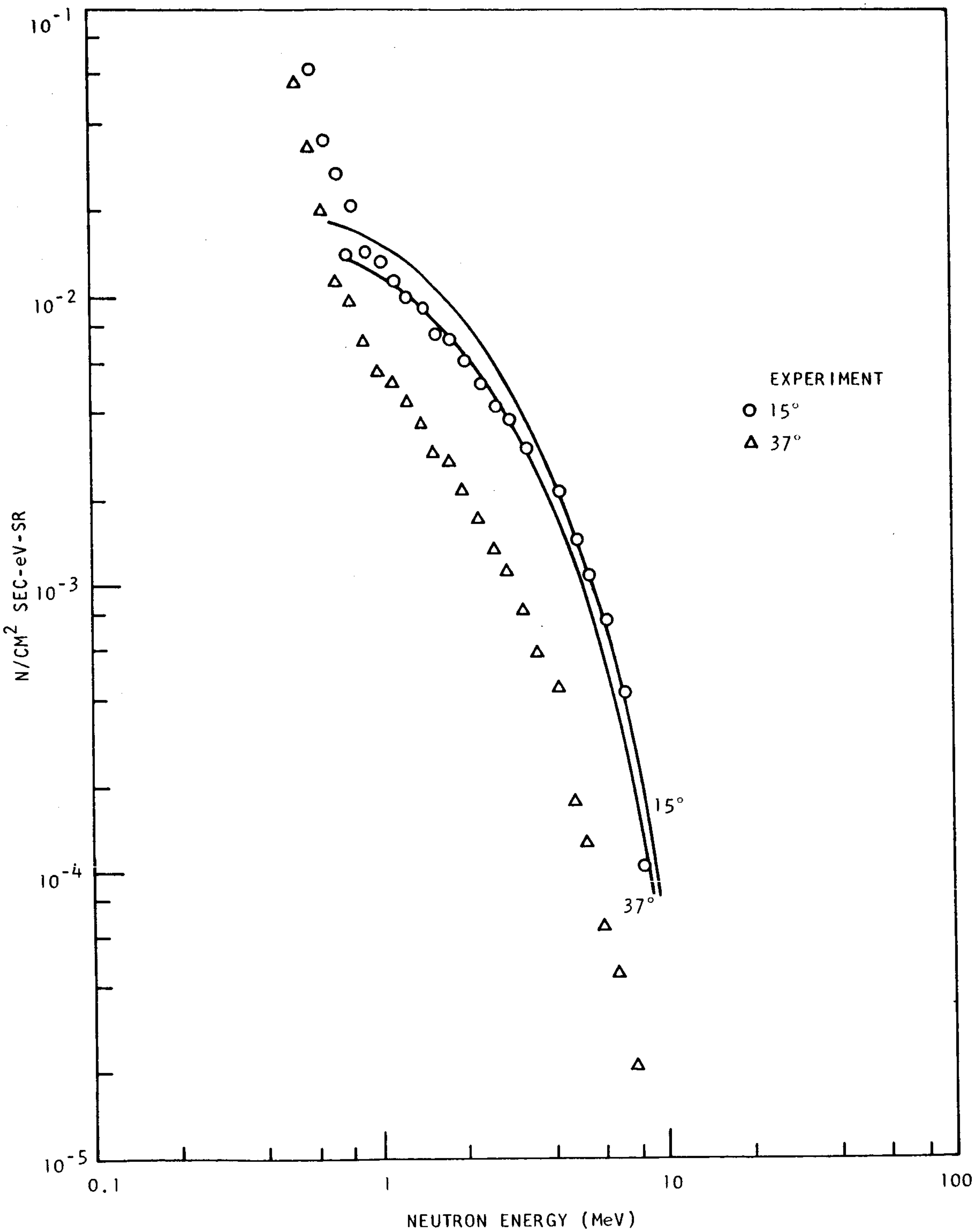

Fig. 15--Measured spectra at 7-in. compared with 11-13-65 GGSN slab calculation.

REFERENCES

1. J. H. Alexander, G. W. Hinman and J. R. Triplett, "GAPLSN: A Modified DSN Program for the Solution of the One-Dimensional Anisotropic Transport Equation", General Atomic Report GA-4972, March 1964.

2. G. D. Joanou and J. S. Dudek, "GAM-II - A B_3 Code for the Calculation of Fast Neutron Spectra and Associated Multigroup Constants", General Atomic Report GA-4265, September 1963.